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THE EFFECTS OF STEREO CONVERGENCE AND OBLIQUITY ANGLES ON THE JUDGED WORTH OF AERIAL PHOTOGRAPHS

TR 723-2

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March 1963

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ABSTRACT

An investigation was made of the effects of stereo convergence and obliquity angles on the judged worth of aerial photographs. Eighteen stereo pairs of the same scene--a model constructed [redacted] were assessed by 16 experienced professional photo interpreters. Three stereo convergence angles--10, 20, and 30 degrees--and six angles of obliquity--0, 10, 20, 30, 45, and 60 degrees--were represented in the eighteen stereo pairs that were assessed.

The stereo pairs were rated by the photo interpreters on a 100-point scale which had verbal anchor points at the top, middle, and bottom. The anchor point at the top was "With this Photography I could fulfill ALL of the detailed requirements." The middle anchor point was ". . . fulfill about HALF of the detailed requirements" and the bottom point was ". . . fulfill NONE of the detailed requirements."

It was found that there were no significant differences in the mean ratings due to differences in convergence angle. There were no differences between 0, 10, and 20 degrees of obliquity. There was a significant drop in the mean ratings from 20 to 60 degrees of obliquity.

Only the last two photo interpreters who participated in the experiment discovered that the scene photographed was a model. Most of the subjects speculated about what part of the country the photographs were taken in. Most preferred not to guess about the type of vehicle the pictures were taken from.

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THE EFFECTS OF STEREO CONVERGENCE AND OBLIQUITY ANGLES ON THE JUDGED WORTH OF AERIAL PHOTOGRAPHS

INTRODUCTION

The purpose of this study was to determine the effects of different stereo convergence and obliquity angles on the judged worth of aerial photographs. Three convergence angles--10, 20, and 30 degrees--and six obliquity angles--0, 10, 20, 30, 45, and 60 degrees--were studied. A stereo pair of a single scene represented each of the 18 cells in Table I.

Table I. The Variations in the Photographs

Stereo Convergence Angle in Degrees	Obliquity Angle in Degrees: 0	10	20	30	45	60
10						
20						
30						

METHOD

Preparation and Specification of the Photographs

The positive transparencies used in the study were prepared by [redacted] 25X1

25X1 [redacted] A 35-mm camera equipped with an 85-mm focal length lens and loaded with Kodak Plus X film was positioned 53 feet above a 1:87 scale terrain model. The nadir scale of the photographs of the model from this position was 1:16,575. For the three largest obliquity angles, the camera was positioned 33 feet above the model, and a 50-mm lens was used. The nadir scale for this condition was 1:17,502. The simulated sun was positioned at an elevation of 60 degrees.

The relation between obliquity and scale is given in Table II.

Table II. The Relation Between Obliquity Angle and Photographic Scale

Obliquity Angle	Photographic Scale
0	1:16,575
10	1:16,831
20	1:18,625
30	1:20,210
45	1:24,755
60	1:35,004

The negatives were processed to approximately unity gamma and contact printed on aerial duplicating film. The prints (positive transparencies) were masked to the picture edges with an opaque, black material and mounted between microscope slide glass.

At nadir, the ground resolution of the transparencies was approximately three feet (2:1 contrast, three bar target resolution) and the film resolution was approximately 20 lines/mm. The scale, resolution, and granularity of the transparencies were such that they could be considered to be 5X enlargements of a system having 100 lines/mm resolution, with Kodak-type 4404 film, and a scale at nadir of 1:82,875.

Subjects

The 16 subjects were professional photo interpreters (PI's). Their average experience as PI's was 6.5 years: the minimum was 2.5 years, and the maximum was 23 years. They worked in different branches of PID and represented a variety of specialties. They were extremely cooperative and appeared to perform very conscientiously the task of assessing the photography.

Procedure

Before the experiment four stereo microscopes were evaluated with a high resolution test target. The quality of one microscope was found to be unacceptable; the other three were used in the experiment.

A subject was seated before the three microscopes and given a randomly selected set of 3 of the 18 stereo pairs. The remaining 15 pairs were placed on the table beside him. The subject was then informally given the following instructions:

> We have 18 stereo pairs of the same scene. The photographs were made under different conditions, but at this time we would prefer not to tell you what those conditions were.
>
> The purpose of having you examine the photographs is to determine their worth and usefulness for photo interpretation. It is our hope that the results we obtain will contribute to the development of better systems.
>
> First we would like you to look at all 18 stereo pairs, get a feeling for what they are like, and then rank them. Place the best one to the right and the worst one to the left here on the table. After you have finished ranking them, we would like you to look at all of them again very carefully. You may use all three microscopes and make comparisons between two or three pairs if you like. On the basis of this second examination, we would like you to place the number of each pair in the boxes along this continuum. (At this point the subject was shown the response sheet and told to read the three anchor-point statements at the top, middle and bottom of the scale on the response sheet. See Figure 1.) To make the scale judgments, consider your own experience and the detailed requirements that have been levied upon you. Avoid ties if you can, for other research has shown that people often make reliable discriminations, or psychophysical judgments, even though they think they are just guessing. Use any magnification you wish. Take as much time as you need, take breaks whenever you wish, and ask any questions you want to--except ones concerning how the photography was made.

With this Photography I could fulfill ALL of the detailed requirements.....

Levied by Intelligence Analysts

100

90

80

70

60

With this Photography I could fulfill about HALF of the detailed requirements.....

Levied by Intelligence Analysts

50

40

30

20

10

With this Photography I could fulfill NONE of the detailed requirements.....

Levied by Intelligence Analysts

0

Figure 1. Response sheet.

Place your name, number of years of experience as a PI, and your specialty at the top of the response sheet.

Please don't talk to other PI's about the experiment. When we're all finished, we'll be happy to discuss the whole thing with you.

Do you have any questions now?

Immediately after the subject completed the task, an informal interview was conducted with him. The following questions were asked:

1. What, in general, did you think of the photographs?
2. Did you notice anything unusual or special about the photographs?
3. In what ways were the photographs different?
4. What things did you look at to make your judgments of the usefulness of the photographs.
5. Did you notice any differences in the amount of obliquity?
6. Did you notice any differences in the amount of stereo relief?
7. Are you familiar with the area? Where do you think it is?
8. What kind of vehicle were the photographs taken from?

After all 16 subjects had judged the 18 laboratory-prepared stereo pairs, they were called back individually to judge four real, vertical, stereo pairs. Three of the pairs were randomly selected from photographs of cloud-free urban areas obtained in recent missions. One pair was from a X mission, one was from a Y mission, and a third was from a Z mission. The fourth pair was an exceptionally "good" frame from a Z mission. All four pairs were processed to achieve approximately the same scale as in the vertical photographs of the model.

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Each subject was given the response sheet he had used to judge the 18 laboratory-prepared photographs. First he placed the pair he had judged "best" on one microscope and the pair he had judged "worst" on another. These pairs served as a reference to his previous judgements. Then he was given the four real stereo pairs and was asked to judge them on the continuum on the response sheet.

RESULTS

The data analysis showed that the ratings of the 30 degree convergence angle stereo pairs at 10 and 20 degrees of obliquity were significantly lower than either the 10 or 20 degree convergence angle pairs. A careful examination of the 30 degree convergence angle pairs revealed that the overall density of one of each of the two pairs was less than the overall density of the others. In short, two of the pictures appeared somewhat "washed out". Consequently, the subjects were asked to rate four additional stereo pairs representing 10 and 20 degrees of obliquity at 20 and 30 degrees of convergence. To do this they used the pairs they had rated best, worst, and average as anchor points. The pictures used in this supplementary study were the same as the ones used initially except that the simulated sun was on the opposite side of the camera, but the angular orientation between the camera and the simulated sun was the same. The data presented here for 10 and 20 degrees of obliquity at 20 and 30 degrees of convergence are those obtained from the supplementary study. The remaining data are from the original study.

The results of the study are shown in Figure 2. An analysis of variance (see Appendix B) showed that there were no significant differences in the mean ratings due to the differences in convergence angle. There were no significant differences between 0, 10, and 20 degrees of obliquity.

#3

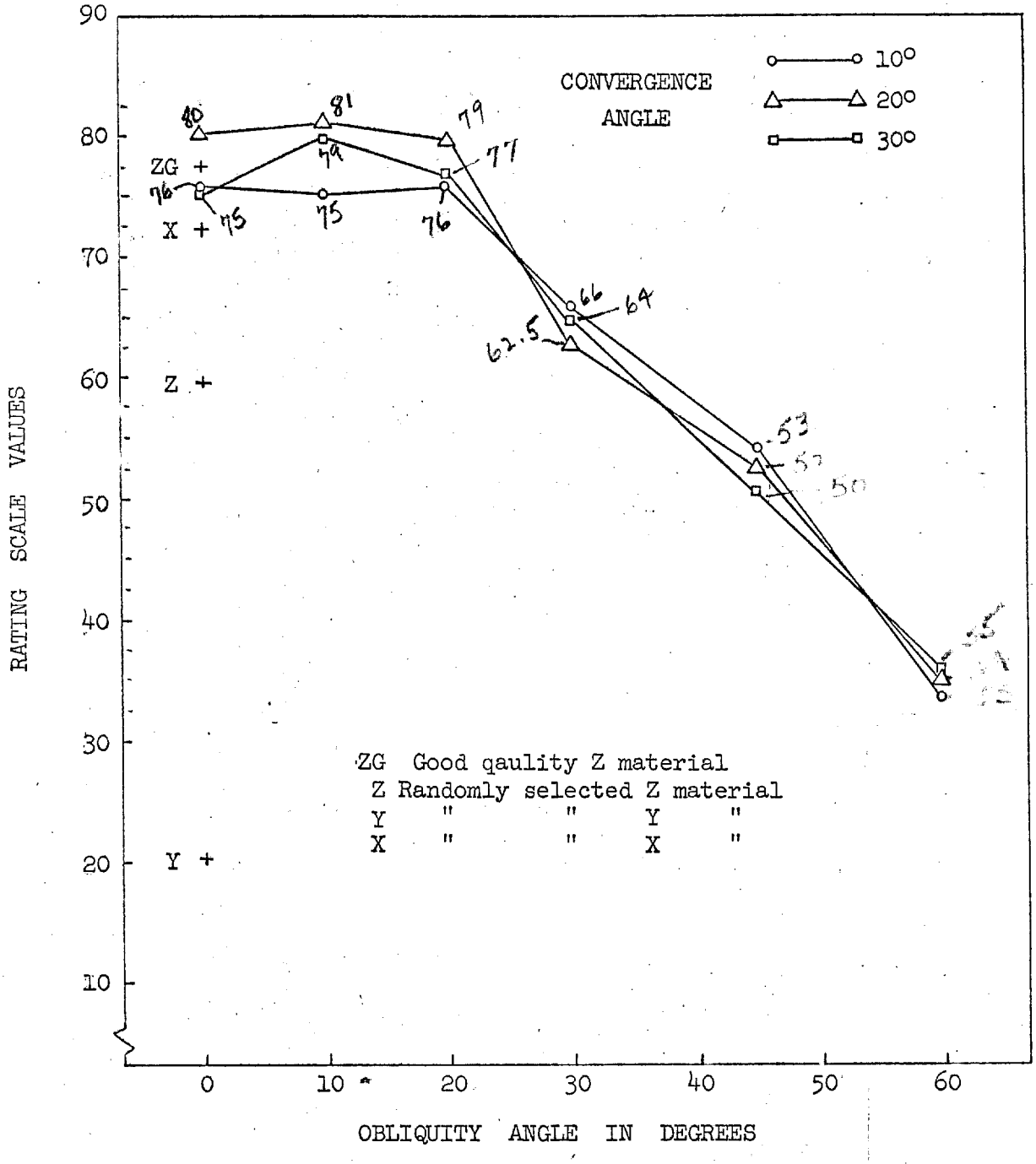


Figure 2. Mean ratings as a function of obliquity angle for three convergence angles. (N = 16)

There was a significant drop in the mean ratings from 20 to 60 degrees of obliquity.

The "good quality" Z material was judged to be equal to the best of the 18 laboratory-prepared stereo pairs. The X was judged to be slightly poorer, but the difference was not statistically significant.

Only two of the subjects discovered that the scene photographed was a model. They were the last two subjects to participate in the experiment.

The means and standard deviations of the ratings assigned all of the stereo pairs used in the experiment are given in Appendix A. Appendix C is an enlarged print of one-half of one of the stereo pairs used in the study. The responses to the questions asked in the post-experimental interviews are given in Appendix D. Figure 3 shows the same data as are given in Figure 2, except that the photographic scale, instead of the obliquity angle, is shown on the abscissa.

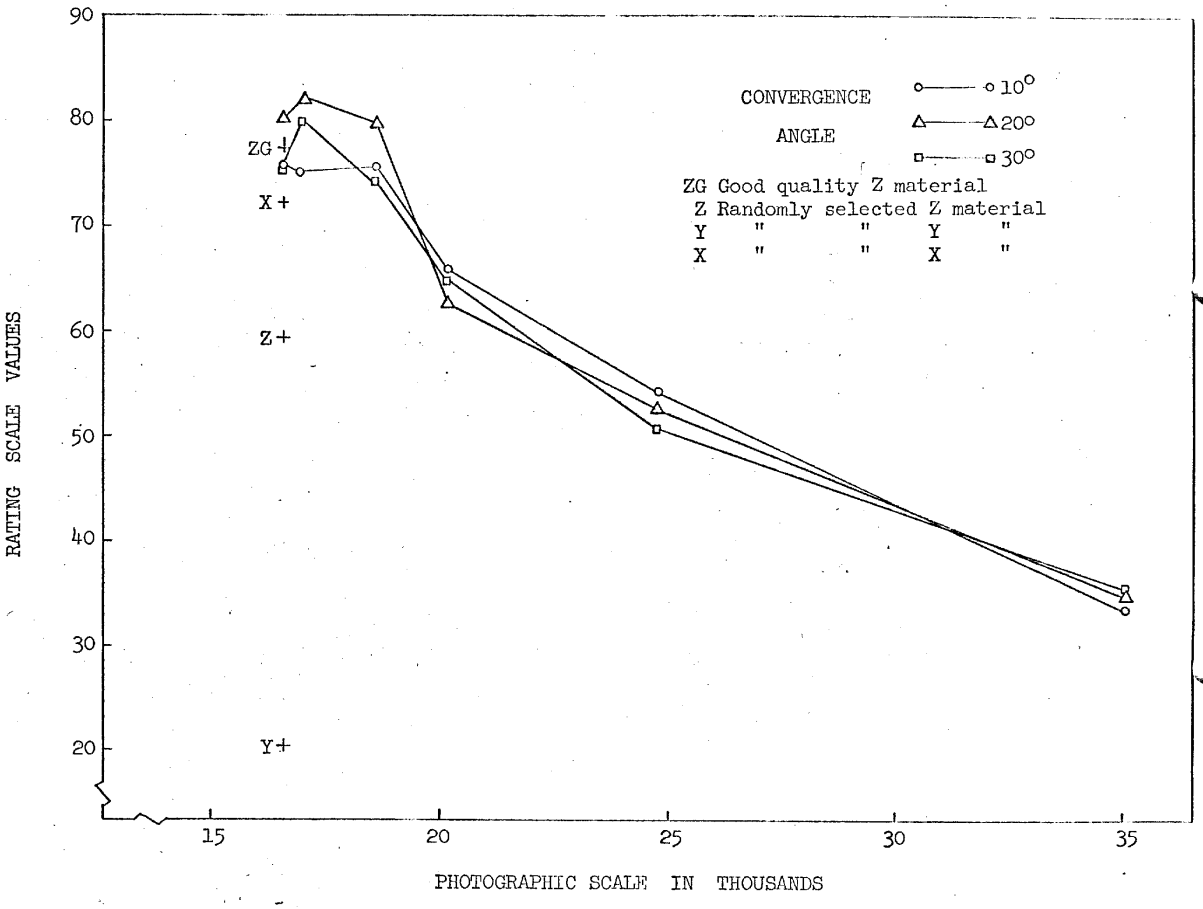


Figure 3. Mean ratings as a function of photographic scale (oblique) for convergence angles of 10°, 20°, and 30°.

APPENDICES

APPENDIX A

Means and Standard Deviations of the
Adjusted Scale Values for the Model Photography*
(N = 16)

CONVERGENCE ANGLE (Degrees)		OBLIQUITY ANGLE (Degrees) 0	10	20	30	45	60	Obliquity Angles Combined
10	Means	76.2	75.4	76.2	66.6	53.9	33.0	63.6
	σ	6.9	9.4	8.1	7.9	7.5	8.1	
20	Means	80.2	82.3	80.1	62.8	52.6	34.9	64.0
	σ	7.9	8.5	11.1	6.7	6.1	6.3	
30	Means	75.6	80.3	76.1	65.0	51.0	35.2	59.5
	σ	9.0	9.5	8.7	8.9	6.4	6.9	
Convergence Angles Combined	Means	77.4	73.2	71.8	64.8	52.5	34.4	

Means and Standard Deviations of the
Adjusted Scale Values for the Real Photography*
(N = 16)

	ZG	Z	Y	X
Means	77.4	59.6	20.[illegible]	72.5
σ	10.5	12.1	13.0	8.1

*Each of the 18 scale values for a subject was adjusted by algebraically adding to it the difference between his mean and the mean of all subjects.

APPENDIX B

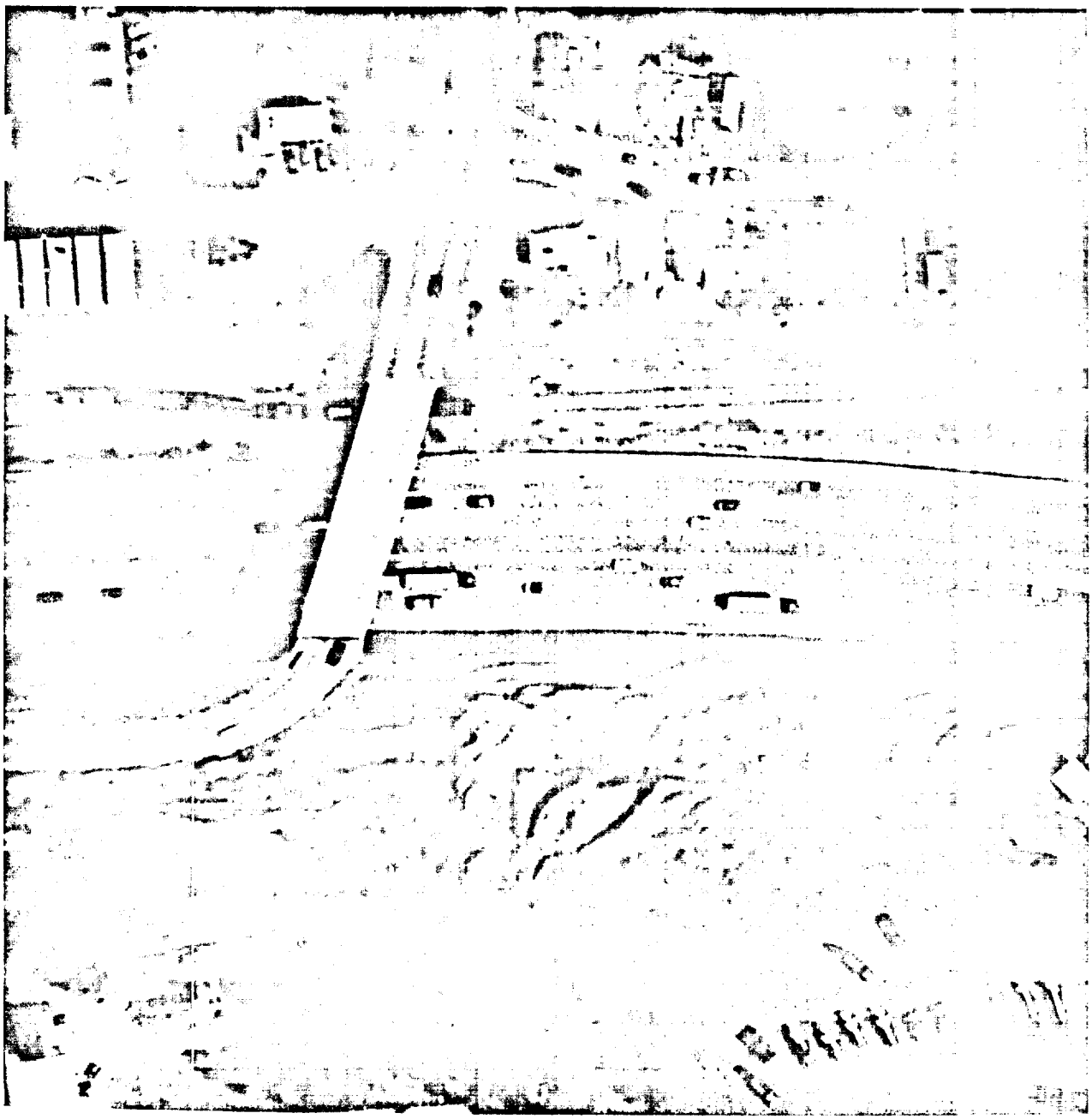
Analysis of Variance of the Scale Values

Source	df	MS	F
Between Subjects (Ss)	15	2,231	
Obliquity (O)	5	14,883	130.6*
Convergence (C)	2	29	0.6
O x C	10	62	1.1
O x Ss (Error)	75	114	
C x Ss (Error)	30	52	
O x C x Ss (Error)	146	58	

*$P < .001$

APPENDIX C

An enlarged print of one-half of one of the stereo pairs.



APPENDIX D

Responses to the Questions Asked in
The Post-Experimental Interviews

1. What, in general did you think of the photographs?

S1 They were pretty good.

S2 I liked the exaggerated stereo with the slight obliquity.

S3 Some were larger scales than others. I liked the larger scale ones better.

S4 The photos in general were quite good. The six rated highest were completely adequate.

S5 Pretty good pictures. The scale is much better than what we use. The detail is good on the majority of them.

S6 They start out pretty good but go to lousy.

S7 Generally, they are good quality.

S8 They are very good. It is difficult to tell the differences.

S9 Some of them were fuzzy.

S10 They were pretty good quality. Some were fuzzy and some were clear.

S11 Why did you pick that scene? I couldn't see very much. I work with much better stuff than that. That is, I have been lately. (He was referring to X photography.)

S12 They are "in between" in relation to real material.

S13 The photos were grainy, quality was not particularly good. (This subject asked if the scene was a model.) He gave the following reasons for asking the question:

a. Shrubs were present in one frame of a pair and not in another.

b. Some vehicles on the freeway had moved while others hadn't.

c. There were no power lines.

S14 They are not too bad, but they tend to "grain out"; you can't use much magnification. In the best pictures you could determine the type of vehicles, perhaps even models, for xample, Ford vs. Chevy.

2. Did you notice anything unusual or special about the photographs?

S1 There were scale differences.

S2 No.

S3 No.

S4 One photo of some pairs looked over-exposed or high-lighted.

S5 All were taken at the same time. The stereo may have been exaggerated in some. Some seemed to be lighter in the center. On some the bridge looked like it was going up hill.

S6 There were two or four originals and the rest were down-graded. 6R and 2R give a true stereo pair--they were probably two of the originals.

S7 The angle between the two photos was changing. The apparent depth or height changed.

S8 No.

S9 No.

S10 No.

S11 The resolution on pairs was different. The resolution on the left, e.g., was not equal to the resolution on the right.

S12 No, I don't believe so.

S13 I suspect that the pictures were of a model.

S14 Well, I don't think so. Some of the vehicles were moving and several were not. Consequently, I don't think this was an actual place but a model board. Nothing I saw would cut mustard. You wouldn't be able to find antennas or cable

ways. What made you think it was a model? I'm pretty sure there were no railings on the bridge. The joints where the curved and straight parts meet on the bridge are too sharp. A truck on the highway is not moving.

3. In what ways were the pictures different?

S1 There were scale differences.

S2 There were differences in obliquity and the amount of stereo.

S3 Scale differences. Contrast differences.

S4 Differences in obliquity. The obliquity was not natural.

S5 Obliquity. Some may have been exaggerated in stereo.

S6 Some were taken with a _____ and others with a _____. One camera had a more stable platform. There were differences in obliquity.

S7 Contrast and apparent depth. I don't think the quality, definition, or resolution changed as much as the contrast appeared to change.

S8 Tone differences.

S9 Exaggerated stereo in some. Some were fuzzy. Differences in obliquity. Some were hard to fuse.

S10 No response.

S11 Stereo height resolution. Contrast scale, but that's obvious.

S12 Some were a little grainy. Some were lighter than others. There were differences in scale. There were differences in the difficulty of getting stereo.

S13 Marked obliquity differences. Scale differences.

S14 Some were much more vertical than others. There was quite a bit more distortion (stereo relief) between some than others.

4. What things did you look at to make your judgments of the usefulness of the photos?

S1 Shadows, cars, and how well height could be measured.

S2 Sharpness of detail, air vents on buildings, missiles, autos.

S3 RR tracks, white line on highway, buildings, roofs, trees, rocks, missiles.

S4 Concentrated on what could be seen in shadows--shadow of the bridge, missiles, vehicles, terrain relief.

S5 Concentrated on the side of the cliff. Parked vehicles--ease of identification. Missiles. Buildings.

S6 Missile wing tips. Turret of tank or tank retriever. Tops of trees.

S7 Buildings with pitched roofs. Autos, aircraft in the top left corner and the rail line.

S8 Configuration of the missiles and their tail sections.

S9 Question omitted.

S10 Outlines of buildings, vehicles, missiles, ventilators, rock formations.

S11 Missiles, tanks, and trucks. General overall appearance.

S12 Terrain features, buildings, cars, missiles, details on cars.

S13 Ventilators, cliffs, objects in shadows.

S14 Vehicles, missiles, dwellings and buildings, over-pass.

5. Did you notice any differences in the amount of obliquity?

S1 I noticed only slight differences.

S2 Yes.

S3 I noticed slight differences.

S4 Yes.

S5 Yes.

S6 Yes.

S7 Yes. About four pairs had greater obliquity than the rest. The obliquity in the remainder was about the same.

S8 Yes.

S9 Yes.

S10 Yes.

S11 I thought I did.

S12 I didn't notice too much. I think the smaller scale was a little more oblique than the larger.

S13 Yes.

S14 Yes.

6. Did you notice any differences in the amount of relief?

S1 No.

S2 Yes.

S3 No.

S4 Yes, it was exaggerated in some places.

S5 Yes, in a couple the stereo relief seemed exaggerated.

S6 Higher rated ones gave greater relief.

S7 Yes, the differences weren't large, but they were apparent.

S8 Some appeared to be better.

S9 Yes, over-exaggerated in some.

S10 Yes.

S11 Yes.

S12 There seemed to be some.

S13 Yes, I noticed pronounced differences in relief.

S14 Yes.

7. Are you familiar with the area? Where do you think it is?

S1 No. I don't know.

S2 No. I would guess El Paso.

S3 No. I don't know.

S4 No. I don't know.

S5 No. No idea.

S6 No. My guess would be California.

S7 No. If I had to guess, I would say the West Coast.

S8 No. Where is it?

S9 No. No guess.

S10 No. No guess.

S11 No. In the U. S. near a military base.

S12 No. But now that you mention it, it might be the D. C. area.

S13 Not asked.

S14 No. I would still guess it's not real.

8. What kind of vehicle were the photos taken from?

S1 Not asked.

S2 I don't know.

S3 I can't tell.

S4 I don't know.

S5 I don't know.

S6 One group with a _____ and the other group a _____.

S7 I would say an aircraft.

S8 I don't know.

S9 No guess.

S10 No guess.

S11 Like a plane or a helo? I don't know. I didn't give it any thought.

S12 No. I don't know.

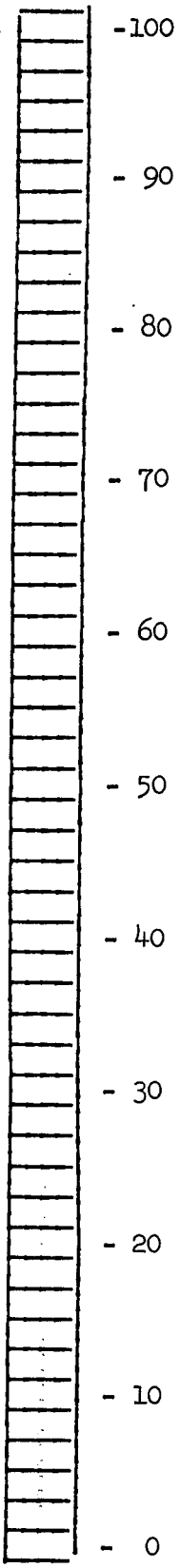
S13 Not asked.

S14 Not asked.

With this Photography I could fulfill ALL of the detailed requirements levied by Intelligence Analysts .....

With this Photography I could fulfill about HALF of the detailed requirements levied by Intelligence Analysts .....

With this Photography I could fulfill NONE of the detailed requirements levied by Intelligence Analysts .....



THE JUDGMENT OF STEREOSCOPIC DEPTH IN PHOTOGRAPHS AS A FUNCTION OF CONVERGENCE AND OBLIQUITY ANGLES

INTRODUCTION

The perception of depth in viewing photographic stereo pairs is often crucially important for making valid interpretations of photographic images. It is known that, within limits, the depth effect experienced by the observer increases as the convergence angle of the camera increases; i.e., as the lateral disparity of the two views of the same object increases. But it is not known how the experience of depth is related to the size of the camera convergence angle or whether the relation is the same for different angles of obliquity--the angle the camera makes with the vertical.

The purpose of this study was to determine, at several angles of obliquity, the relation between the size of the convergence angle and judgment of relative depth.

METHOD

Subjects. The subjects were 10 professional photointerpreters and ranged in experience from 2.5 years to 15 years with a median of approximately 4 years.

Photographs and Viewing Equipment. The photographs were of a scale model which contained a freeway, a freeway overpass, buildings of different heights and shapes, vehicles, foliage, and various terrain features.

The model was photographed at five convergence angles—10°, 15°, 20°, 25°, and 30°—at each of three obliquity angles—0°, 30°, and 60°, making a total of 15 stereo pairs. In addition to the stereo pairs, a non-stereo pair was prepared at each obliquity

angle, making a total of six pairs of photographs at each obliquity angle. The non-stereo pairs were unrealistic in that the sun azimuth was not the same in each half.

The model was illuminated with lights to simulate the sun and the diffuse lighting created by atmosphere. The "sun" azimuth, "sun" elevation (60°), and modulation transfer function were the same for all experimental conditions.

Each photograph was mounted between glass slides. The pairs of photographs were viewed with a [redacted] stereo-zoom microscope at a magnification set by each photointerpreter. 25X1

Procedure. Each photointerpreter made 15 comparisons among six pairs of photographs (5 stereo pairs and 1 non-stereo pair) at each obliquity angle or a total of 45 comparisons.

To control for possible order effects, the 45 pairs to be compared were presented to each photointerpreter in a different random order.

The photointerpreter's task was to answer the question, "Which of the two stereo pairs has the greater relief?"

RESULTS

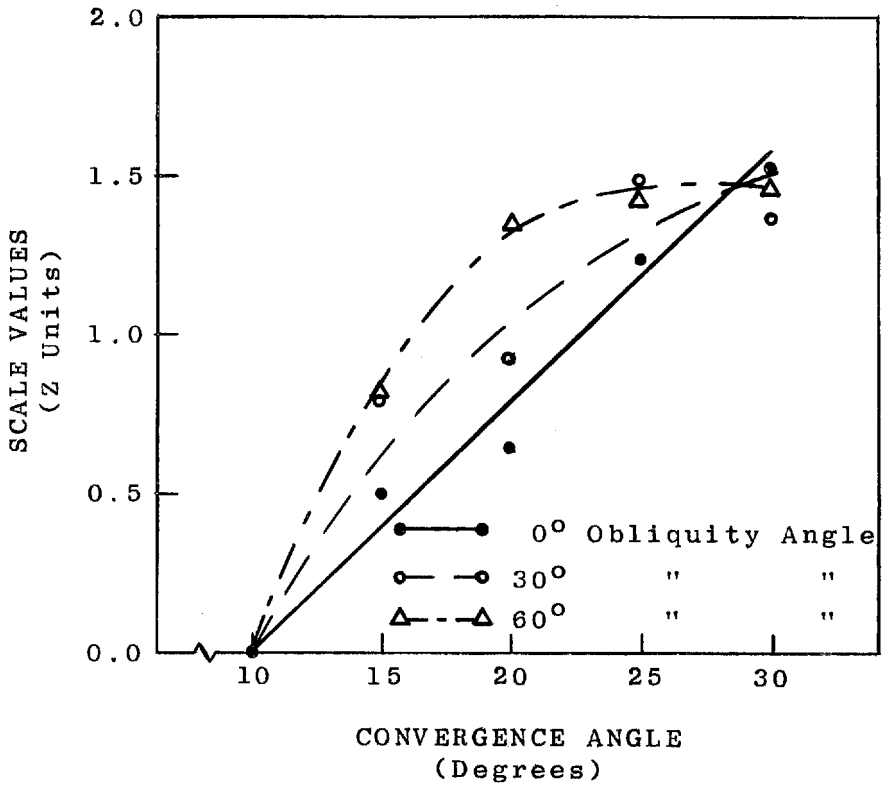
A pair comparison scaling technique* was used to scale convergence angle. Only the comparisons of the stereo pairs (10 comparisons at each obliquity angle) were used to accomplish the scaling.

The proportion of times each stereo-pair was judged as having more depth than another pair was computed. These proportions were transformed to Z scores. (Z's are values of deviates corresponding to areas under the normal curve.) The use of this transformation

*In J. P. Guilford, 2nd ed., Psychometric Methods. New York: McGraw-Hill, 1959, Ch. 7, p. 160.

is based on the assumption that Z values are on a linear psychological scale.

Because the pair-comparison scaling technique does not locate a psychologically meaningful zero point, the origin of each function was set arbitrarily at 0.0 on the ordinate. Consequently only the slopes, but not the heights, of the functions may be compared.



Scale values of convergence angles at each of three angles of obliquity. The functions were fitted visually to the data point.

The results show that at each obliquity angle the scale value (amount of depth seen) increases as the convergence angle increases. At 0° obliquity, the relation between convergence angle and scale value is linear—equal differences in convergence angle produce equal differences in the amount of depth seen. But at 30° and 60° angles of obliquity, the relation is curvilinear and the curvilinearity is greater at a 60° than at a 30° angle. At these two

obliquities, equal differences in convergence angle did not produce equal differences in the amount of depth seen. For example, at a 60° angle of obliquity, a change in convergence angle from 10° to 20° produces a change of about 1.30 scale units, but a change in convergence angle from 20° to 30° produces a change of only about 0.15 scale units—a much smaller change in the amount of depth seen.

Only a small sample of subjects was used in the present study; consequently the functions shown in the figure are not precise. However, the results do seem to indicate that as the angle of obliquity is increased from 0° to 60°, the relation between convergence angle and the amount of depth seen becomes increasingly curvilinear.

Inspection of the judgments made by individual photointerpreters revealed a rather unexpected finding: two of the photointerpreters were apparently unable to see differences in depth. Of the 30 comparisons of the stereo pairs, one photointerpreter made 15 correct judgments and another made 13 correct judgments; chance performance was 15 correct judgments. (A judgment was counted as an error when the stereo pair produced with a smaller convergence angle was judged as having more depth than the one produced with a larger convergence angle.) In addition, of the 15 comparisons of the non-stereo pairs with the stereo pairs, the same two photointerpreters made four and three errors respectively. That is, they judged the non-stereo pairs as having more depth than the stereo pairs. This was particularly surprising since the two halves of the non-stereo pairs did not have the same sun azimuth.